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Taking into account of habitat/housing classification in the sewage sludge quantification in the cities of sub-saharan african countries: implementation in the city of Yaounde (Cameroon)

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Abstract:

The difficulty of quantifying sewage sludge in most of the major cities of the Sub-Saharan African countries is mainly due to the lack of control of habitat problems. We performed the quantification of the sludge in a city that takes into account the classification of the habitat. A definition of the quantification of sewage sludge in a habitat enabled the stratification of a given agglomeration and we estimated after a static processing that the total volume of sludge is a function of some parameters, using the method of "enhanced specific production" which is more adapted to the context of sub-Saharan African countries. An application was made to Yaoundé city in Cameroon on 120 sewerage systems/ Wastewater facilities drained between may and august 2018. Out of the 120 wastewater facilities drained, the sludge storage devices are shared by several households, i.e. (2,56±1,74) households for an average of (12,8±8,7) persons. In 2018, Yaoundé city produced 283,175 m^3 of sewage sludge, of which 51.7% could be drained by truck (146,514 m^3), or 401 m3/day. Only 52.4% of the sludge was collected (210 m^3/day) and transported to the dump site which is an anarchic dumping site in a peri-urban area of the city. This enables to deduce that the quantification of sludge as evaluated so far has been overestimated as well as the investment needs, thus limiting for the country, new extensions in neighborhoods or new cities where the demand is however solvent.

Keywords - **Sewage sludge, habitat/housing classification, quantification, sub-saharan Africa.**

I. INTRODUCTION

The rapid growth of cities in developing countries and the proliferation of spontaneous housing areas make the problem of urban sanitation crucial. In Africa and Asia, it is estimated that 65-100% of homes with sanitation systems have self-contained facilities that are not connected to a sewer system [1]. These facilities consist mainly of latrines or septic tanks. When they are full, their contents are evacuated by draining trucks or manual drainers. These pumpout services, essential to enhance the quality of life environment, are however little or not planned by the Authorities. According to the World Health Organization (WHO), there are 2.6 billion people worldwide who do not have access to adequate sanitation systems and nearly 1.1 billion people continue to defecate in the open air [2]. For developing countries in particular, a United Nations report on the Millennium Development Goals (MDGs), estimated in 2008 that almost a quarter of the population in developing countries had no sanitation systems, while 15% used inadequate sanitation facilities. In addition, defecation in the open air by the majority of the population endangers the entire community, given the increased risk of contracting diarrhoeic diseases, cholera, verminous infestations, hepatitis and other associated diseases [3]. In most major cities in developing countries in general and those in sub-Saharan Africa in particular, wastewater and excreta sanitation issues are a major concern [4], [5], [6]. Most cities do not generally have a sewer system; excreta are collected in individual sewage systems installed at the residential level [7]. However, in Burkina Faso, for example, from 2005 to 2015, the sanitation facility was directed towards increasing the rate of access to sanitation through the implementation of these autonomous wastewater facilities, which generates large quantities of sewage sludge, with its anarchic management and disposal facility in the city and its neighbourhoods [8]. Indeed, although several methods of quantifying the production of sewage sludge have been developed worldwide, they are not always adapted to the contexts of African cities where most of the wastewater facilities are poorly accessible and adapted to mechanical emptying [9], [10]. In order to meet the need the sewerage system, autonomous systems are preferred for their more accessible costs compared to the sewer system, despite the health risks associated with the management of sludge from these wastewater [7]. However, it is almost impossible to deal with sewage sludge issues without worrying about habitat. Urbanization has become a global problem since the beginning of this century and to date more than half of humanity lives in urban areas. In developing countries in general and those in sub-Saharan Africa in particular, this phenomenon is taking place at an unprecedented rate, and causes enormous difficulties for managing urban networks and in particular the liquid sewerage of sewage sludge. Although all these cities in developing countries do not have a single profile, most of them have common characteristics. Africa is the least urbanized continent on the planet, with 11.3% of the world’s urban population, and the sub-Saharan region is the least urbanized on the continent. However, cities in the region are expanding rapidly. According to United Nations forecasts, Africa will surpass Asia as the fastest urbanizing region in the world in 2025 [3]. Facing all these disproportionate habitat needs, draft solutions, of general scope, such as those resulting from the Vancouver Conference (1976), which again led to a failure due to the transposition of the Northern countries' habitat product models [11]. Yaoundé city, for example, is made up of several types of spontaneous neighborhoods, covering an area of 1530 ha or 60% of the total area of residential neighborhoods. These failures result logically from the virtual impossibility to define a policy of sludge management in these megalopolis of developing countries without taking into account the classification of the habitat. Although the rate of urbanization is not the same in all these countries, the rate of increase is much higher in sub-Saharan Africa. This explains the high concentration of the urban population in large cities. An isomorphism can be found between the habitat and the production of the sewage sludge of these inhabitants. Since these dwellings are of different types, sludge production is also a function of housing. Thus to quantify the sludge in a city, far from using the norms of the Northern countries whose dwellings are standardized, the universe of the mother population is divided, each exclusive subset of elements corresponding to a homogeneous group (stratum) will also have a quantification. This study aims to take into account habitat classification in the quantification of sludge, with a view to proposing efficient processing wastewater facilities and subsequently experimenting with other technological alternatives for processing these sludge, accessible to communities in the context of developing countries in general and sub-Saharan African countries in particular. Indeed, although several methods of quantifying the production of sewage sludge have been developed worldwide, they are not always adapted to the contexts of African cities where most of the wastewater facilities are little accessible and little adapted to mechanical pump out [9], [10].

II. FACILITIES AND METHODS

A. Presentation of study site

Yaoundé city is located at 3°5'of latitude North and 11°31'of longitude East, approximately 200 km from the Atlantic coast, and occupies a 310 km2 accidental site. Capital of Cameroon and the second largest city of the country, it includes most of the administrative superstructure of the country and part of the companies' headquarters. The city has about 3.1 million inhabitants in 2018. With an average annual growth rate of 3.5%, the population of Yaoundé will reach 4.7 million in 2030 [12], [13]. The management of domestic wastewater in the city is mainly done through autonomous sewerage systems or individual sanitation (septic tanks, latrines, etc.). Indeed, in 2018, 99% of households in the city used the autonomous sewerage system [2]. This is the case in most cities in sub-Saharan Africa [14]. However, the level of organization of the individual sanitation and sewage sludge management subsector is relatively low in Yaoundé [15]. The Urban Community of Yaoundé (CUY), which has competence in the field of sanitation, does not have sufficient human and financial resources, the legal framework and the organization necessary for an efficient individual sanitation. Gaps are noted on each link in the value chain of autonomous sanitation, from the residential toilet to the recovery of sewage sludge, through collection/transport and processing. Among other difficulties, we can list for illustrative purposes, the lack of Sewage Sludge Processing Station (STBV) that negatively impacts on Public Health and the Environment [9]. At the habitat level, the classification is varied and complex. It is characterized, in quality as in quantity, by an absolute failure which can be explained by both demographic factors (population increase, rapid urbanization) and socio-economic factors (underdevelopment of productive forces). Most urban dwellings are generally informal and, in some cases, overcrowded and of poor quality, the actual estimates of existing housing stock, future demand, and overall quality of existing housing stock (both formal and informal) are complex and difficult to achieve. The rigorous evaluation of the quantity of sludge must be based on the production of housing, which in turn is an aggregate of several other components.

B. Methods

Sewage sludge

Sewage sludge refers to fresh or partially mineralized liquid or solid sludge resulting from the storage of sewage discharge/human waste and excreta in structures not connected to the sewer system [16]. These are: traditional latrine, VIP latrine (Ventilated Improved Pit), manual flush latrine, public toilet, sump, septic tank and all-water tank. Depending on the type of waste water facility, the consistency and composition of the sludge are variable. In fact, sludge from fast-filling structures that use little water such as traditional latrines, VIP latrines and public toilets is highly concentrated and fermentable, whereas sludge from septic tanks after a more or less long stay of 4 to 15 years is partially mineralized during anaerobic digestion processes; it is biologically more stable [7]. There are generally two methods of pumpout in African countries, namely manual emptying which mainly concerns latrines and mechanical emptying in the case of septic tanks and all-water tanks [17]. In the first case, it is concentrated sludge and in the second case it is diluted, which facilitates the emptying. Indeed, report that the septic tank is a modern wastewater facility for preprocessing (settling and digestion) of sewage sludge, which justifies that the concentrations of pollutants are lower than at the level of latrines [7].

C. Sampling facilities and protective equipment

The sampling facility made up of a cup, cooler, funnel and bottles (glass and plastic) while the personal protective facility made up of multiple-use gloves, single-use gloves, nose masks, gowns and safety shoes.

D. Methodology for characterizing habitat classification

Habitat characterization in sub-Saharan Africa is a tedious exercise and many characterizations do not take into account the context of the countries of this region whose water and sanitation remain the main problem of their concerns. A survey and then an analysis of the data must be carried out in order to ensure the representativeness of the sample according to its configuration, a stratification must be made so that each type of neighbourhoods is represented. The household surveys were carried out as a sampling frame from a file with prior enumeration zones.
The model put in place therefore consisted, after the establishment of a database, of using an organizational chart that deals with the survey forms from the database.
The objective is that from the survey form, find the greatest number of similarities with the characteristics data per type of habitat and deduce the type of dwelling.
The processing program functions as follows:

- At the entrance, we have a matrix with scattered habitat characteristics and a table with different types of habitat standing.
- There is a correlation between habitat characteristics and habitat types.

Each habitat characteristic is associated with a table with the modalities of the corresponding characteristic.

Example:

	Characteristics		Modalities
3	Type of toilet	1	internal toilet with water flushing
		2	private external toilets with water flushing
		3	shared toilets with water flushing
		4	Private latrines
		5	common latrines
		6	Nature

- The program functions on the basis of points granted to different types of housing, for each characteristic. For each type of accommodation, a meter is reserved to accumulate the points awarded.
- The correlation matrix between habitat characteristics and habitat type serves as the basis for assigning points, whenever there is a coincidence between the elements of the matrix and the data from the survey forms.
- For each survey form, the different characteristics and associated modalities are covered by adding 1 or 0 each time to the standing meter (type of dwelling) if there is a coincidence or not with the elements of the matrix.
- At the end of the journey, the different values of the standing meters are compared and the largest is chosen. If this number is greater than or equal to 9 (minimum tolerance level, the maximum being 14), the housing type is that of this type of meter. Otherwise, the dwelling is classified as *"other type"*.

Habitat characteristics being the main source of drinking water, method of sewage disposal, type of toilet, method of household waste disposal, main route of access to the home, location, status of occupancy of the dwelling, main material of the floor, main material of the walls, main material of the roof, type of structure, number of bedrooms in the dwelling, main source of energy for cooking, main mode of lighting.

E. Sludge collection methodology for quantification

Data were collected using the following techniques:

- Individual and group interviews of stakeholders (town hall, municipalities, drainers);
- truck routing for two weeks (16 rotations corresponding to 19 draining operations) to assess distances done, number of rotations, operating times and drained volumes;
- characterization of a sample of 120 autonomous sanitation structures (latrines, septic tanks): estimation of the dimensions (length, width, diameter, depth), capacities of each wastewater facility;
- report mapped data using MapInfo software;
- exploitation of survey data completed by CREPA on a sample of 378 households randomly selected from the different socio-economic strata of the city;
- reconstitution of the exploiting account from the mechanical pump out over the period 2002-2003. The quantities of sludge were estimated using the method based on the specific production (quantity of sludge produced per capita per day) and taking into account the classification of the city's habitat.

Because of the non-existent data for Yaoundé city, we used the values proposed by [18] : 1 liter/day/capita for septic tanks and 0.2 liter/day/capita for dry latrines. The estimated quantities of sludge produced (Q in m3/year) were estimated using the following formula [18].

$$Q = 365 * (PFS * + \frac{Qfs}{1000} + PLS * \frac{QLS}{1000}) \qquad (1)$$

- Q (m^3/year): quantity of sludge produced;
- PFS (capita): number of septic tank users;
- PLS (capita): number of dry latrines users;
- QFS (l/capita/day): specific production of sewage sludge for septic tanks;
- QLS (l/capita/day): specific production of sewage sludge for dry latrines.

As for the quantities of sludge pumped out (mechanical emptying) per year, the method is based on counting the number of emptying towers and truck volume per year [19].

$$Q = 365 * N * V \qquad (2)$$

- Q (m3/yr): quantity of sludge pumped out
- N: Total number of truck tours per year
- V (m3): Truck volume

III. SIMULATION RESULT

The model put in place has enabled to obtain four types of standing of housing in Yaoundé city including the high standing, the medium standing, the spontaneous standing and the spontaneous peri-urban standing. The characteristics of each of these habitat standings are summarized in the following table:

Table 1. Housing classification of Yaoundé city

	High standing	Medium Standing	Spontaneous Standing	Spontaneous peri-urban Standing
Type of structure	- Dispatched /isolated house - Modern Villa - Building	- Dispatched /isolated house - Modern villa - Building - Multi-unit house/House with several dwellings - Concession/saré	- Dispatched/isolated house - Multi-unit house/House with several dwellings - Concession/saré	- dispatched /isolated house - Multi-unit house/House with several dweelings - Concession/saré
Construction equipment	- Lasting	- Lasting - Semi lasting	- Lasting - Semi lasting - Occasional	- Semi lasting - Occasional
Washroom	- internal toilet with	- internal toilet with	- common toilet with	- Private Latrine

	water flushing -	water flushing - internal toilet with water flushing - internal toilet with water flushing - Private Latrine - Common Latrine	water flushing -Private Latrine - Common Latrine - Nature	- Common Latrine - Nature
Lighting	- Electricity	- Electricity - Gaz - Petroleum	- Any lighting mode	- Any lighting mode
Cooking energy	- Electricity - Gaz	- Any type of cooking energy	- Any type of cooking energy	- Any type of cooking energy
Water Supply	- Indoor faucet/tap - Mineral water - Drilling	- Any mode of water supply	- - Any mode of water supply	- - Any mode of water supply, except the indoor faucet
Sewage Disposal	- Septic Tank	- Any Method of Sewage Disposal	- Any Method of Sewage Disposal	- Any Method of Sewage Disposal

This stratification of the habitat in the city facilities the sewage sludge collection, which enables to quantify them with better precision.

Out of the 120 households that were drained during the observation period, 81.7% are households with septic tanks. It appears that in Yaoundé city the septic tanks are more drained than any other autonomous device. The remaining wastewater facilities drained are single pits (11.7%) and public toilets (6.6%) (Figure 1).

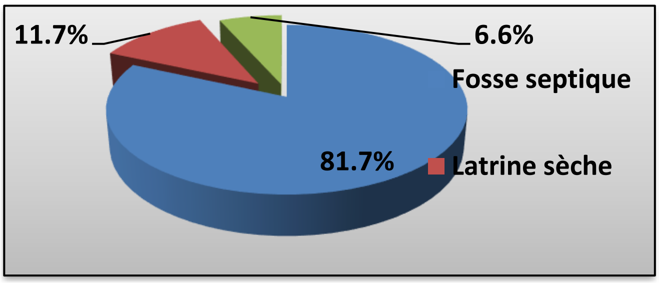

Figure 1: Distribution per type of autonomous systems drained during the observation period.

About 80% of the sewage sludge collected comes from septic tanks.
But out of the 120 pumping out followed during our observation period, 89% were carried out by households and only 4% by hotels and the rest were public toilets.
Contrary to what might be expected, 65.8% of the mechanical emptying carried out was by households living in medium-quality dwellings, 22.5% by households living in high-quality dwellings and 11.7% by low-quality households (Table 2).

Table 2: Distribution of the number of drains/pumping out per type of occupied habitat (Source: Achievements from field surveys)

Type of habitat	Number	Percentage (%)
High standing	27	22,50
Medium standing	46	38,33
Spontaneous standing	31	21,67
Spontaneous peri-urban Standing	26	17,50
Total	120	100,00

Out of the 120 wastewater facilities emptied, the sludge storage systems are shared by several households (2.56 1.74) or an average of (12.8 8.7) people.

The sludge accumulation rates were calculated on the basis of the amount of sludge actually drained, measured after volume recovery before and after draining. The accumulation time (duration between two drains) and the number of users served by the system (achieved after the household survey whose wastewater facility is drained). The specific production of sludge per capita depends on the standing of the habitat (Table 3).

Table 3: Average sludge production depending on habitat standing

(Source: Field survey achievements)

Type of habitat	Medium l/capita./day	Minimum l/capita./day	Median l/capita./day	Standard deviation l/capita./day	Maximum l/capita./day
High standing	0,36	0,22	0,37	0,13	0,44
Average standing	0,33	0,16	0,31	0,10	0,39
Spontaneous Standing	0,31	0,17	0,29	0,09	0,37
Spontaneous Peri-urban Standing	0,27	0,18	0,25	0,08	0,33

It can be noted that there is no difference between the sludge accumulation rate between the high and medium standing areas. On the other hand, the rate of accumulation of sludge appears to be lower in households with spontaneous or spontaneous peri-urban housing.
The achievements presented in Table 4 show that sludge production is higher in septic tanks 0,356 l/capita/day , in those with tanks, and low in latrines 0,21 l/capita/day .

Table 4: Specific sludge production per type of storage device (Source: Field survey achievements)

Type of autonomous device	Medium l/capita./day	Minimum l/capita./day	Median l/capita./day	Standard deviation l/capita./day	Maximum l/capita./day
Septic tank	0,356	0,24	0,34	0,13	0,387
Traditional Latrine	0,21	0,16	0,18	0,17	0,33

IV.DISCUSSION

In the study area, there is a four-layer habitat classification that is more spread out than the existing one, which consists of three strata, which enables a better sludge quantification. There is also a significant difference between the production rate of sludge in septic tanks and single tanks. This is due to the fact that single pits are not watertight in the study area. Much of the sludge produced is diluted by the waste water /sewage thrown into the pits and infiltrated. In the surveys carried out on 1100 households the specific production found is

0.5 l/capita/day different from that of 0.7 l/capita/day obtained in the same city by the data from the town hall. The limit of this value comes from the fact that it is really not the specific production of sludge that has been evaluated. This value also incorporates supernatants which in the normal functioning of the pit are discharged into the sump. It is only during the pumping out that the supernatant blocked in the pit by default of circulation of the wastewater is drained. The result achieved in this study is similar to that achieved in Burkina Faso on single-pit sludge by Kaonda in 2006 (0.3 l/capita/day), as well as that of (0.20 l/capita/day) in the city of Kumasi in Ghana [18]. But this result is far from that achieved in South Africa by Norris in 2000 on septic tanks (0.08 l/capita/day) [20]. The rate of accumulation of sludge in septic tanks can olso depends on the duration of the drain [21]. The specific production of sludge in septic tanks increases from 0.35 l/capita/day at the start of use of the tank to 0.16 l/capita/day after 3.5 years of use with a production of 0.23 l/capita/day between the second and third years [22]. The specific production of septic tank sludge well above 0.23 l/capita/day would therefore be signs of malfunction (or misuse) or premature emptying.

V.CONCLUSIONS

This study aimed to contribute to the consideration of habitat classification in enhancing the quantification of sludge in sub-Saharan Africa cities.

The methodology used is as follows: we first conducted field surveys and the data collected were combined with existing data and the sludge quantification model resulted from the statistical processing of these data using the regression method. The application of our model to Yaoundé city (Cameroon) enabled us to estimate the specific enhanced sludge production. The results achieved are much lower than those achieved by the technical services of the Urban Community of Yaoundé. We can say with little risk of being wrong that the quantification of sludge has so far been over estimated. This has resulted in the over-sizing of processing wastewater facility, which has not helped obtaining funding for sewer system extensions in some cities where demand is potentially solvent; This highlights the economic importance of the proposed model.

Regarding the quality of the results achieved by the method of quantification of the sewage sludge taking into account the classification of the habitat, we can recommend it to the other cities of the sub-Saharan African countries but making sure that their classification of habitat is well refined.

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